# Georgescu-Roegen's entropic model: a methodological appraisal

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## Abstract

**Purpose** – This paper aims to tackle in turn the merits and limits of Nicholas Georgescu-Roegen's entropic model, as well as its implications for the methodological discourse in economics. This appraisal of the Georgescu-Roegen's work emphasizes the emergence of the entropic nature of the economic processes as a paradigm *à la* Kuhn of explanation in social economics.

**Design/methodology/approach** – This work provides a critical assessment of the entropic model's main conceptual pillars, namely the role of mathematical formalism and the natural imagery of *irreversibility*. This discussion takes them in turn and develops a critique from a methodological point of view.

**Findings** – The focus of this work is that the proposed epistemological reconstruction of economics is vulnerable to attacks from two methodological objections. The first deals with the change of metaphor from the "pendulum" of mechanics to the "hourglass" of thermodynamics. The second refers to the changes this replacement of metaphors brings about as to the relevance of the formalism of the discipline.

**Originality/value** – This material has gathered arguments to show that the intellectual concurrence of the arguments onto the field of physics makes the methodological value of the new paradigm of entropy not transcend into a new logic of reasoning in economics. The limits of this approach stems from the same rationale for which it has got its revolutionary stature: what it proposes consists of a scientific discourse based on a mixture of evolutionary biology, economics and thermodynamics, which may open up new original and insightful perspectives, but which has never been justified on terms of *economic* nature alone.

**Keywords** Research methods, Economic processes, Economic models

**Paper type** Conceptual paper

## Introduction

Nicholas Georgescu-Roegen (1992) summarised, in a defeated mood, his *life philosophy* with an enigmatic assertion: "After long years I have concluded that for the results of one's struggle the place from which one runs against a current matters enormously". By that time, he had been waging for more than three decades to persuade the economics establishment that its methodological discourse ought to be based on a new epistemology he calls "the entropic model". His approach evolved from isolated technical critiques of the neo-classical conceptual platform to a coherent, distinct, radical exposition of economics on evolutionary premises. It is the purpose of this paper to tackle in turn the merits and limits of the entropic model and discuss its implications for the methodological discourse in economics.

A voluminous literature of reviews of Georgescu-Roegen's contributions amassed continuously both before and after his death in 1994, but the verdict is hardly favourable as Mark Blaug notes: "[his] works have received virtually no critical discussion from economists" (quoted in Daly, 1999). So, the reader would certainly be tempted to follow Mirowski (2001) and wonder, "What all the fuss is about?" The common criticism ascribes the unfortunate result to either "unfounded"



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interpretations of the relevance of the laws of thermodynamics to the economics of production (Khalil, 2004) or to a neglect of the post-war advancements of neo-classical economics in fields like "game theory, decision theory, and operations research" (Mirowski, 2001).

This appraisal of the Georgescu-Roegen's work emphasizes instead the emergence of the entropic nature of the economic processes as a paradigm *à la* Kuhn of explanation in social sciences and, particularly, in economics. The next section continues with a presentation of its path-breaking epistemological developments and attempts to discern the valid elements about knowledge in economics which ought to be part of any future representation of the nature of economic reasoning. Against his manifest discomfort with the severe limitations of the conventional approach in economics, Georgescu-Roegen's innumerable forays into the philosophy of science substantiate his vision of a new analytical representation of economic processes based on the entropy law.

At the same time, this thesis concurs with the view that his parallel effort to mould this epistemology into a convincing method failed to live up to expectations. A subsequent section provides a critical assessment of its main conceptual pillars, namely the role of mathematical formalism and the natural imagery of irreversibility. The final section concludes with considerations on the uncommon role the entropic model plays in the present quest for a new method of economics.

## The emergence of a paradigm

The Georgescu-Roegen's intellectual destiny witnessed so intimately the tribulations of the rise to distinction of the entropic model from isolated interrogations to the full-fledged academic establishment of ecological economics that it can undoubtedly make up a case in the study of scientific revolutions. Its mark spanned several generations of economists in three distinct phases.

Firstly, he was widely acclaimed as an "accomplished mathematician" (Daly, 1999) and, in Samuelson's felicitous accolade, "an economist's economist" – albeit an accidental one: "I said to myself that … I have nothing to do with economics and I do not wish to become an economist, never!" (Georgescu-Roegen, 1988).

His earliest contributions, he confesses, "ran with the current, which was then to expand the legitimate use of mathematics in economics" (Georgescu-Roegen, 1992) and thus secured him in the 1930s a highly auspicious reception at Harvard. There, eminent scholars of the neoclassical school tried to elicit his attention: Samuelson (1996a) remembers Georgescu-Roegen as an young deity during the 1939 Harvard Seminar; Frank Taussig asks him to "serve as an honest broker on a controversy between A.C. Pigou and Milton Friedman concerning Pigou's recipe for measuring the elasticity of demand" (Georgescu-Roegen, 1988); and Joseph A. Schumpeter proposes a joint authorship of a treatise on theoretical economics, an offer Georgescu-Roegen repentantly declines (Georgescu-Roegen, 1992).

Secondly, Georgescu-Roegen transformed himself into a non-conformist economist whose inquiry into the epistemological foundations of the neoclassical economics school was an unintended consequence of his efforts to correct the conventional approach.

He begins his "conventional" period with the *Pure Theory of Consumers' Behaviour* by taking the "opportunity for correcting some errors that have slipped into the most

recent papers on the subject and, finally, for developing an alternate theory of the nature of indifference curves" (Georgescu-Roegen, 1936) and finishes it three decades later with *Analytical Economics*, an impressive volume in which almost any reading stands for a devastating attack on the neo-classical economics. His education enables him to expose mathematical "missteps" of several notable mathematical economists like Vilfredo Pareto, R. G. D. Allen, Milton Friedman, or dispel "mathematical fantasies" in the works of many contemporaries (Georgescu-Roegen, 1988, 1992, 1993).

Thirdly, it is Georgescu-Roegen the mentor who sets the pattern of thought for the newly established ecological economics school. His research into the biophysical dimensions of economic activity inspired the creation of the International Society for Ecological Economists and the founding of its journal *Ecological Economics* (Maneschi, 2000). Its exponents owe much to Georgescu-Roegen's works on *entropy* and duly acknowledge his pioneering contribution (Daly, 2004).

In its new role, Georgescu-Roegen resuscitates the economics discipline by trying to instil its methodology with breakthrough physics achievements as represented by the laws of thermodynamics. In the energy crisis-stricken climate of the 1970s, his contributions in pure economics such as the demand theory and probabilistic preferences or the production theory are sidelined in favour of a much more *en vogue* model he had just developed: the irreversible transformation of matter and energy along an economic process. *The New Palgrave: A Dictionary of Economics* gives due credit to the economist who pioneered a bio-economic conception of economics and to the entropy law that "is the most economic of the physics laws" (Zamagni, 1996a).

All together, the accidental, non-conformist and inspirational economist advanced an epistemological reconstruction of economics based on the laws of thermodynamics. Georgescu-Roegen finds with the entropy law, as defined by the second law of thermodynamics, the solution for the controversial issues of economic inquiry which he revealed in his early studies. It remains subject to further investigation how the two main fields of knowledge – economics and thermodynamics – were connected in the first place. Whatever the answer, the dual origin of the entropic model engenders a heterodox approach to the analytical representation of economic processes, with intermingling concepts and juxtaposed perspectives. At one time, one reviewer commented that his discussion "wholeheartedly devoted" to economics does not explicitly make use of the entropy law, while his digression in the philosophy of science is not "explicitly about technical economics" either (Schlegel *et al.*, 1973).

Three themes seem to dominate the epistemological discourse based on the entropic model:

(1) the problem of time as a distinct factor in analytical representation of a production process;

(2) dialectics as opposed to arithmomorphism as the logical foundation of economics; and

(3) the limitations of the mathematical models.

This discussion takes each of them in turn and develops in a subsequent section a critique from a methodological point of view.

*Discussion on time*

In 1856, the German physicist Rudolph Clausius provided the mathematical proof that, in a physical system which is isolated from the outside world and hence subject to the principle of conservation of energy (the first law of thermodynamic systems), heat is continuously and irrevocably converted from a source that involves a difference of temperature from a warmer object to a colder one, and never in reverse. The physicist coined the law entropy (the second law of thermodynamics), a word based on the Greek term entrope, meaning a turning toward, to describe the probable behaviour of isolated systems to produce mechanical work by turning energy, to which Georgescu-Roegen adds as the fourth law of thermodynamics, and matter from available into unavailable. Entropy has become a measure of the energy that is no longer available for work during a thermodynamic process.

The irreversible flow of energy and matter which is implied by an entropic transformation has made Georgescu-Roegen assert that "entropy is the sole temporal law in physics" (Georgescu-Roegen, 1996, p. 141). In a succinct formulation, time direction is a function of change of entropy from order-low entropy in the form of useful energy-to increasing disorder-high entropy in the form of unavailable energy. Duration as an interval between the past and the future becomes the epitome of any representation in social sciences: change needs time to occur or to be perceived.

The ultimate goal of the economic process – the humankind's well-being or "enjoyment of life" in Georgescu-Roegen's parlance – so becomes inescapably linked to the passage of time: in their material existence, organisms survive on the condition that they are capable of capturing low entropy from the environment ("the struggle for entropy"). In opposition to the neo-classical vision of consumers' utility maximization under constraints of optimal allocation of scarce resources, Georgescu-Roegen envisions a life implacably challenged by the irreversible degradation of energy and of matter which "sets a more dreadful limit, a limit on the survival of the human species on this planet" (Georgescu-Roegen, 1979). The social system should be so seen as a milieu in which (economic) value originates in finite sources of low entropy and is irrevocably destroyed in time rather than created through the mechanism of pricing. The optimization problem turns its spatial dimension – a given endowment with resources – into a temporal one: "enjoyment must be so arranged that the total pleasure during one's entire life should be a maximum deal" (quoted in Maneschi, 2000).

This change of perspectives engenders profound consequences as to the way economists perceive the nature of economic processes. The notion of cause in physics is not adequate for the study of economics and biology, in recognition of the evolutionary processes inherent to the economic activity as Alfred Marshall first suggested in his *Principles*. What distinguishes a biotic life – that is an eco-system with living creatures – is the consumption of low entropy which is not purely a physical manifestation, but irreversible transformations for the ultimate purpose of the "enjoyment of life".

Because of entropy, historical facts give birth to controversies which are not easily tractable within the deterministic framework. This epistemological interpretation resonates well with the philosophy of science. Dragan and Demetrescu (1991, pp. 44, 86) enlarge the issue by making reference to the works of Ludwig von Bertalanffy (General Systems Theory, 1972) and Walter Buckley (Sociology and Modern Systems Theory, 1967) to represent causation in historical systems. The "direct cause – effect" connection, which is at the core of the mechanistic representation, may take various

forms: final outcomes can be achieved by starting from different original conditions and along different paths (the equi-finality principle) and similar initial conditions may develop into dissimilar final states (the multi-finality principle).

Georgescu-Roegen (1996, p. 142) points to the erroneous treatment of time in standard economics which makes behaviour dependent exclusively on present conditions; any temporal location eludes history by assuming invariants of economic phenomena. The continuum of time necessarily relates the social environment to evolutions of qualitative change and thus to "the continuous emergence of novelty" (Georgescu-Roegen, 1979), and not to discretely distinct – arithmomorphic in his terminology – descriptions of economic processes. In contrast to the logical, rational characteristic of the latter approach, which makes possible syllogistic reasoning and calculations, the former facet of reality is not amenable to explanations from "the already known phenomenal laws" (Georgescu-Roegen, 1979). To which ones instead?

*Discussion on dialectical reasoning*

Half of the Georgescu-Roegen's core message comes in clear-cut fashion: the arithmomorphic fragmentation of the continuum of the social reality which characterizes the methodological approach in modern economics is the main cause for our incapacity to explain what happens within its limits; "a unitary seamless reality opposes division into arithmomorphic pieces" (quoted in Dragan and Demetrescu, 1991, p. 180). The logic of this scientific reasoning deals with distinct symbols, like $m$, $2$ or $\infty$, invariant concepts that make the investigation powerless in dealing with propositions like "Culturally determined wants are higher than biological needs" (Georgescu-Roegen, 1992). Propositions about the observed phenomena follow a logical order, for instance, of the type that "the measures of a triangle's angles add to the measures of two rectangular angles"; one proposition follows logically from another one.

On the other hand, there is a confessed understanding of the limits of the model. Georgescu-Roegen is aware that the innovative approach the entropic model suggests as to the treatment of time may inspire a new method of scientific inquiry he calls "dialectical reasoning", but also repeatedly says Georgescu-Roegen (1992; 1996, p. 51) that "a new Aristotle might set dialect[ic]al reasoning on as a solid basis as the traditional logic". What the Roegenian epistemology provides instead consists of a conceptualization whereby Georgescu-Roegen differentiates between analysis and dialectics, and so the analyst has reasoning opposed to memory, the invariant opposed to history, with the observation that the "dialectical concepts" are deprived of the character of law as suggested by Hegel or Marx (Georgescu-Roegen, 1992).

A special feature of social events makes any scientific inquiry based on arithmomorphism hardly tractable: the existence of "dialectical penumbras" that surround the attempt to investigate the temporal events, a process in which the penumbra creates an infinite dialectical regression that opposes the "vacuous boundary" of an arithmomorphic concept.

Georgescu-Roegen identifies the critical issue in the third principle of logic, that is one may not have both A and non-A true. Nevertheless, on observing *tertium non datur*, dialectical reasoning unites opposite concepts by a penumbra – "it is within this penumbra that both A and non-A are true" (Georgescu-Roegen, 1979) – and can thus adequately represent qualitative change, which implies analysis of *contradictory*,

like elements of dictatorship in a democracy, or varying facts, like interpersonally comparable wants. If one changes an arithmomorphic feature of a square, say one of its angles, the square ceases to be a square, but one can indeed represent a modified dialectical concept, say democracy under various circumstances of minimum voting age, and the concept will still preserve its validity. As it happens, a social scientist's list of fundamental concepts like "justice, democracy, good, evil, abstraction, workable competition, entrepreneur, farmer, occupation, belief" (Georgescu-Roegen, 1979) falls under the dialectical order of the theory.

The entropy law seems to stand for the perfect representation of this logic. It reflects "basic limitations of all living creatures" (Georgescu-Roegen, 1992) by their continuous struggle to get control of low entropy sources in an environment where both matter and energy are subject to irreversible degradation. The scientist's representations of social facts change their intrinsic value with the passage of time as an inexorable consequence of increasing entropy. In contrast to standard economics that rests on a circular flow embodied in the principle of energy conservation, the economic activity results in irreversible changes in the environment.

The great corollary of the entire conceptual system is expressed by the definition of value. Economic scarcity continues to be the main constraint to the achievement of what Georgescu-Roegen calls the output of any economic activity, "the enjoyment of life", only that the economic value now lies in "the entropic degradation of energy and of matter in bulk" (Georgescu-Roegen, 1992). Against the hedonic principle of conventional economics, of continuous growth and variations of "self-identical elements" such as investments or utility, the entropic model opposes conservation of resources and neglect of modern consumerism.

*Discussion on mathematical models*

Georgescu-Roegen's early forays into the analytical power of mathematical models made him reach a verdict which hardly needs any commentary: "economic phenomena are not governed by a mathematical network" (Georgescu-Roegen, 1992). Nevertheless, his choice as to the use of mathematics is somewhat equivocal. On the way, much of the early radicalism turned into a new form of calculus, this time faithful to a different paradigm in physics, i.e. entropy. It is so more pertinently to assume that his attitude should be seen as a position against the mechanistic representation of economic processes with its reversible nature that infringes on the entropic principles rather than a genuine abhorrence to the abuse of mathematics, opposition which at any rate justifies alone the unsympathetic reception from his neo-classical fellows.

Georgescu-Roegen takes any occasion to reaffirm his faith in Blaise Pascal's "immortal" dichotomy between *esprit géométrique* and *esprit de finesse*. The French scholar warned that "mathematicians are lost in the field of finesse where the principles are so subtle and so numerous that one must have a very delicate and very clear sense to perceive and judge them correctly and justly" (quoted in Dragan and Demetrescu, 1991, p. 79). His trying at reconciling the two produces a model of scientific inquiry "which must necessarily aspire to be quantitative and hence mathematical" while giving due credit to "the absolute necessity of historical and institutional studies in social studies, hence in economics" (Georgescu-Roegen, 1979).

The pieces of evidence were gathered in successive phases, from disparate findings of the early period to the comprehensive system of "analytical

representation of facts" that is presented in his Entropy Law and the Economic Process (1971).

He opposes the Cowles Commission, which in the 1930s was seeking for a mathematical procedure to predict the evolutions on the stock market, on the ground that historical, unique processes cannot be described by a mathematical, "necessarily ahistorical formula" (Georgescu-Roegen, 1988). Georgescu-Roegen' remark about "the ineptitude of predicting economic futures by econometric models" was considered one of the "irritating blunders" by the adherents of the neo-classical school (Georgescu-Roegen, 1992).

The contact with the inter-war realities of Romania, a developing, agrarian country, provokes a harsh critique of the cornerstone of the standard analysis – the marginal criterion – which simply does not hold in such circumstances: the marginal price does not maximize the national product in economies characterized by scarcity. He instead makes a substantial plea to give the institutional norms a key role in understanding that type of economies: "In conditions of scarcity, income distribution is made not according to marginal pricing, but according to some institutional rules" (Georgescu-Roegen, 1992).

Georgescu-Roegen's answer gets more elaborated with the fundamental distinction he makes in *Economic Theory and Agrarian Economics* (1960) between the exact pattern of natural sciences and the analytical scheme of social sciences (Georgescu-Roegen, 1996, p. 321). This methodological delimitation paves the way for the construction of the logic of reasoning based on the analytical representation of facts: understanding in any field of study is based on two sorts of concepts, arithmomorphic and dialectical (Georgescu-Roegen, 1996, p. 104).

The method of inquiry is determined by the class/order of the phenomena under investigation. According to Georgescu-Roegen (1996, pp. 120-1), the scientist confronts three types of facts: rational of the first order, whose representation is essentially based on algebraic deductions; rational of the second order, whose representation depends primarily on empirical observations; and, finally, rational of the third order, whose representation is highly unpredictable, as the correlations between their constitutive elements are decisively afflicted by irregularities. It is this last category of facts which appear particularly important for the study of economic phenomena. The two opposing views on random (the deterministic and the in-deterministic) are "the two ends of one and the same bridge between human understanding and the actual world" (Georgescu-Roegen, 1996, p. 67).

Is there a way to handle this indeterminacy within the limits of scientific investigation? Georgescu-Roegen thinks that the answer consists of a radical transformation of mathematical models in the sense that the stochastic form is the sole possibility by which the natural laws can be represented, instead of being a peripheral form. This conception lies at the core of the new proposed representation of phenomena. On the one hand, it enables a better analytical refinement based on randomness, where chances of any fact to occur are arbitrary, and haphazardness, which describes facts that may repeat themselves. On the other hand, it introduces probability associated with natural phenomena as a dialectical concept defined by randomness, "for randomness implies irregularity, unlike the desultory haphazardness that irregularity is regular" (Georgescu-Roegen, 1992).

## The entropic model: a critique of its methodological value for economics

The conceptual construction of the entropic model is immense. In the eyes of one sympathetic reviewer, besides being a "fundamental work ... it is also incomplete, at times inconsistent and both over- and underemphasises different topics" (Schlegel *et al.*, 1973). The focus of this section is that the proposed epistemological reconstruction of economics is vulnerable to attacks from two methodological objections. The first deals with the change of metaphor from the "pendulum" of mechanics to the "hourglass" of thermodynamics. Despite contrary claims, the latter leaves unscratched the edifice of the traditional logic too. The second refers to the changes this replacement of metaphors brings about as to the relevance of the formalism of the discipline. The answer is a disconcerting "none", the more so one of the main Georgescu-Roegen's disappointments with the conventional thinking concerns its emphasis on "analysis" and neglect of "dialectics".

### *The metaphor of pendulum vs the metaphor of hourglass*

Georgescu-Roegen struggled along his entire lifework to persuade his fellow economists that economics should receive a different treatment as to its methodological approach; the mechanistic view of the classics is both flawed and unsuitable to the study of economic facts, he argued. In spite of the merits of the ensuing epistemological construction, there are indications that his approach has never left the field of physics.

Georgescu-Roegen followed Karl Marx and did not consider the economic process as an isolated or closed system, but, relying on support from evolutionary biology, an extension of the biological evolution. The economic life is seen as an irreversible degradation of entropy, free energy is transformed into bound energy, and not as a pendulum swinging toward an equilibrium position, the mindset which set the foundation of neo-classical economics. The neoclassical representation is reducible to replaceable inputs, recyclable matter and energy conservation; however large the swings, the pendulum will always set in motion a circular flow. The adoption of the second law of thermodynamics however required a paradigmatic change. The metaphor of hourglass was instead adopted to suggest the irreversible and irrevocable path of energy and matter towards extinction.

So, the economist is asked to substitute one obsolete metaphor for a new one devised along with the advancement of physics. Neither his work, nor his commentators' opinions place the entropic model outside physics. Henri Guitton (1996, p. 134), introducing the entropic model, has no doubt that the philosophical rationale of economics should rely on physics foundations and praises Georgescu-Roegen for the effort to bridge the gap between theoretical physics and economics. Onicescu (1996, p. 177), one of his mathematics professors in the formative years, also admires his contribution to explaining both physical and economic phenomena; the entropy law is regarded as a unifying principle for natural and social sciences. Mirowski (1996) places Georgescu-Roegen's contribution on the worthy path of finding an answer to an urgent analytical problem of economics – Why so many economists and engineers stay firm in their incomprehension of the physical character of the economic process?

As his work reflects it, the economic phenomena depend on the physical and chemical laws of people's internal and external environment. It is this natural process so heavily embedded in living creatures' organization of (economic) activities that makes every detail governed by the entropy law, a physical transformation.

His view on social conflict, for example, is an illustration of why the epistemological constraints do not reposition the scientific understanding by means of an economic method proper. He remains much attracted by the insightful approach of Plato to the theory of elites, but departs from the antique wisdom by saying that the reason for which social conflict will extend into the indefinite future is not mankind's division into classes, but the looming struggle over low-entropy resources. In fact, it seems that the only compassionate consideration about human species' behaviour Georgescu-Roegen makes consists in its determination "to have a short but extravagant existence" (Georgescu-Roegen, 1992). He borrows metaphors from physics and biology, but is not yet resolved to discard the neoclassical postulate altogether, as it refers to a natural imagery applied to social interaction, along with its embedded formalism.

*The recourse to formalism*

Georgescu-Roegen's famous remark which concludes his study on *The Nature of Expectation and Uncertainty* (1958), "there is a limit to what we can do with numbers, as there is to what we can do without them", is in fact preceded by an abstract study in probabilistic theory in which no reference is made to whatsoever social or historical context. It is just an early example of his indecisive departure from formalism. After the publication of his opus on *Entropy Law* (1971), one commentator also noticed that his quantitative and theoretical writing is accompanied by "virtually no empirical data" (Schlegel *et al.*, 1973).

Revolutionary and non-conformist though he came to be known within the economists' community, Georgescu-Roegen is at ease among his neo-classical fellows. His autobiographical notes speak of the consumer choice being related to a topological axiom which means that "the indifference planar elements form a convex structure relative to the origin of coordinates" and the solution he proposes leads to "a stochastic distribution of some particular varieties at every point of the commodity space" (Georgescu-Roegen, 1988). He finds the book of the agrarian economist Virgil Madgearu (*Agrarianism, Capitalism, Imperialism*, 1936) a profound study that deserves (at the time of writing in 1993) to be translated in English for a broader recognition, although that Romanian economist cannot "establish any dialogue about points of pure economic theory" (Georgescu-Roegen, 1993). He admits that the literature of purely mathematical exercises "correspond to absolutely no facts, not even to physical ones" (Georgescu-Roegen, 1992), but provides an extended investigation following the line of Bauer-Sweezy thesis on the *Mathematical Proofs of the Breakdown of Capitalism* (1960).

Georgescu-Roegen's choice of using mathematics does not result evidently from his epistemology. Several instances would have suggested a novel interpretation of the economic method as well: his emphasis on dialectical penumbras to reveal interpenetrations of historical events; his manifest sympathy for such anti-neoclassical schools of thought as Marxism, German historical school or American institutionalism; or his harsh critique of the futile arithmomorphism. According to Georgescu-Roegen, the economist should continue to be well versed in mathematics for two well-reasoned justifications. First, the traditional benefits of any quantitative analysis should be preserved whether for the economy of thinking it produces (Georgescu-Roegen, 1996, p. 322), to point to flaws in verbal economists' reasoning (Georgescu-Roegen, 1996, p. 327) or to master the "engineering economics" in those circumstances when an optimizing

solution is required (Georgescu-Roegen, 1979). Second, the Roegean epistemology rests on a technical apparatus based on the probability theory powerful enough to reveal the indeterminism associated with the dialectical concepts. So, the whole spectrum of economics domain falls again under the prevalence of mathematical tool-kits.

A title of one of his chapters reads "mechanics vs thermodynamics" (Georgescu-Roegen, 1995), a preference highly suggestive of the methodological battlefield which paved the way towards the adoption of the entropy law. It is this game of continuous search for low entropy that determines the fate of humanity. One may perceive the human action only in relation to its struggle to overcome the entropic barrier: the search for new territories, like for example the discovery of the New World in 1492 or the astronomic journey to the Moon, are planned under increased pressure stemming from the scarcity of natural resources (Georgescu-Roegen, 1995, pp. 51-2).

A perfect natural process thus frames the constraints of economic activity, this time not in a system that is closed and circular, but open to sources of energy – mineral deposits, solar radiation, etc. – and degradable. The dialectical penumbra, as the typical analytical representation of any process, becomes defined on the coordinates of flows, stocks, and funds (the material basis of the process). The new formalism mirrors a change of paradigm, not a new method of inquiry: both the formulation and the formalism of the entropic model are based on the same logic of analytical representation of the natural processes.

## Concluding remarks

With his entropic model, Georgescu-Roegen meets the exigencies of the most convivial criticism of the neo-classical economics: the new economics should try to learn from physics not to replicate it (Mirowski, 1996, p. 218). Georgescu-Roegen's remarkable incursion in the philosophy of science proves that physics may remain the beloved of the methodologist, but any attempt to go beyond the present dissatisfaction with the economic method is deemed to remain fruitless in the absence of a broader intellectual contribution from within the realm of economics.

This material has gathered arguments to show that the entropic model embodies an analytical inquiry of the economic processes based on a vast philosophical quest for epistemological reinterpretation in fields of study as diverse as statistics, biology, history, and, of course, physics. This vast methodological journey has produced profound results. The new perspective on time, arithmomorphism and dialectical reasoning helps the observer get a better understanding of the economic events. There however remains a problematic aspect of all this emblematic effort, for it sets out as a devastating account on the epistemological importance of one field (mechanics) of physics just to advance the logic of another field (thermodynamics) of physics. And all this to the noble task of reforming economics! At least two arguments seem to suggest that the task of creating a new method remains unfulfilled.

First, Georgescu-Roegen addressed the economists' audience, even if it had been more appropriate to look for the physicists' attention. The practical implications of the entropic model as illustrated by its "minimal bio-economic programme" (Georgescu-Roegen, 1995, pp. 102-11) represent considerate suggestions on the issues of matter and energy in the global terrestrial environment subject to the scarcity of resources. His plan of action on such points as unhindered migration or control of population growth results as a consequence from the natural process of degradable energy. It is on this particular

allegation that Georgescu-Roegen's firm belief that science in not able to stop the irreversible use of the utilisable energy has received strong opposition from scientists like Ilya Prigogine, supported by economists like Robert Solow who argued that "the world can, in effect, get along without natural resources" (quoted in Georgescu-Roegen, 1992). The physics realm does not extend a more favourable welcome to his conceptual developments either, whose reception varies from outright ignorance (Jenkins, 2005) to open criticism (Khalil, 2004).

As for his fellow economists, Georgescu-Roegen confessed that he never crossed "intellectual swords" with them (Georgescu-Roegen, 1992). Such an authoritative text as *The MIT Dictionary of Modern Economics* (Pearce, 1992) finds no entry for "entropy law" or "Georgescu-Roegen". When asked to enlist what he would consider as G-R's most important scientific contributions, Mirowski (1996) remarks that most of them were either appropriated or left in oblivion by other economists. It is by no means an astonishing result of all his great achievements in the field of economic science.

Second, the entropic model does not effectively reach to the task which it initially assumes, namely to provide a refined analytical form for understanding the evolutions surrounding the enjoyment of life. Several shortcomings of the model are responsible for this outcome like its obsession with physical transformations or its simplistic answers to fundamental economic problems. It is probably this latter result which stands out as one of the main causes of its methodological failure. It could be mentioned here that the cultural patterns are unconvincingly described by a dichotomised representation of economic systems between advanced and agrarian economies; or that the humankind is so far knowledgeable of only three sets of viable technological advancements, namely husbandry, the mastery of fire, and the steam engine (Georgescu-Roegen, 1992), all "Promethean" recipes that prove capable of self-sustaining contributions (inputs) to economic progress.

Georgescu-Roegen's commanding intellectual stature creates resources that feed the entropic model from innumerable sources of knowledge. It is for this reason that its revolutionary concepts and insightful perspectives have made a lasting contribution to the methodological reconstruction of economics. The limits of this approach stems from the same rationale for which it has got its revolutionary stature: what it proposes consists of a scientific discourse based on a mixture of evolutionary biology, economics and thermodynamics, which may open up new original and insightful perspectives, but which has never been justified on terms of economic nature alone.

In the entropic model, economic activity remains as impersonal as the mechanistic outlook describes it; it is about converting scarce matter and energy of low entropy and of economic value (solar energy and natural resources) into high entropy (pollution, waste, dissipated heat) to produce output in the form of life enjoyment. The intellectual concurrence of the arguments onto the field of physics makes the methodological value of the new paradigm of entropy not transcend into a new logic of reasoning in economics. In both contents and formalism it stays inseparable from the present methodological discourse. In a modified perspective of scientific inquiry, it is as if the chemical analysis of water were conditional on people's perception of taste and not exclusively on its molecular composition. In reverse, the same holds true for economics: one cannot think of social events in *sui generis* investigative representations of flows of energy and matter even if, indeed, the human species must accommodate itself with the natural scarcity.

The entropic model replaces the natural imagery of circular motion of the pendulum with the one of irrevocable conversion of the hourglass, and correspondingly adopts a modified formalism, that is, the very reason against which this new methodological inquiry was devised in the first place. To be sure, it is not his continued use of formalism that makes the methodological proposition vulnerable; it is because it does not play the role Georgescu-Roegen thinks it should play in solving problems which are dialectical in nature. On the contrary, the formalism in the sense of using mathematics signals no significant departure from the neoclassical edifice.



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